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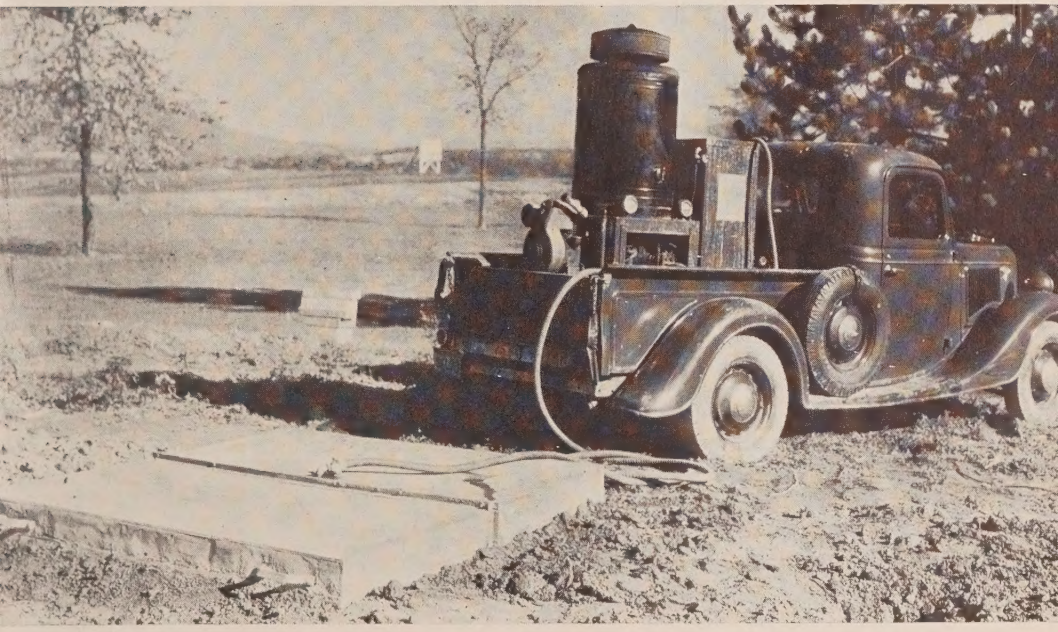

STEAM-VAPOR GENERATOR USED IN THESE EXPERIMENTS

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DIGEST

This study deals with a new method of soil treatment using an apparatus which combines heat and chemicals. The principle of operation differs from that of the steam boiler in that water or chemical solutions are vaporized while being pumped through heated coils. When a volatile chemical, such as formaldehyde, is used in a solution, separation of the chemical by distillation is prevented and the concentration of the chemical is constant.

This method effects penetration of formaldehyde into the soil as deeply as steam, making it possible to shorten the period of treatment with the inverted pan and increasing the efficiency of the method in treating cold or wet soils. The initial moisture content of the soil is a limiting factor in the penetration of the steam-vapor.

Small quantities of formaldehyde appear to be very effective when applied as a hot vapor. Most seeds may be planted 24 hours afterward without being injured. This method reduces the need of seed treatment.

The cost of treating soil by this method compares very favorably with that of other common methods of soil disinfection.

COMBINING HEAT AND FORMALDEHYDE FOR SOIL TREATMENT[1]

KENNETH G. BEACHLEY[2]

THE IMPORTANCE of ridding the soil of various disease-producing organisms, weed seeds, and insects, in the production of healthy seedlings in outdoor seedbeds and greenhouses, has long been recognized. The processes employed to that end usually have been referred to as sterilization or disinfection. While these terms are not accurate, they have been generally used and it is believed that their further use will not result in misunderstanding.

Surface firing was the first means of partial sterilization and in some sections of the country it is still used. In the southern tobacco areas, where wood is plentiful, it is still the common practice. The baking process is a modification of surface firing. Usually the soil is supported by a piece of sheet iron on standards, with a fire beneath.

Chemicals were first used in soil treatment about 1867, when formaldehyde was introduced by the German chemist, Hoffman. Today, many chemicals are effective and satisfactory in some respects but are not so efficient as steam or heat in the control of weeds, fungi, bacteria, nematodes, and insect pests.

Formaldehyde is the chemical most commonly used in soil disinfection. Recommendations for the application of this chemical vary. A common one is to drench the soil with a solution of one part formaldehyde to 50 parts water at the rate of one-half gallon per square foot. It is unsafe to seed for approximately two weeks after this treatment. For treating small quantities of soil, Guterman and Massey (8) found that more concentrated solutions of formaldehyde may be used by mixing it thoroughly with the soil. Formaldehyde dusts—formaldehyde incorporated with various pulverized materials—have been advocated as a satisfactory means of controlling damping-off fungi (19). Other chemicals, such as glacial acetic acid (4), carbon bisulphide, mercuric chloride (18), chloropicrin (7), sulphuric acid (9), copper sulphate (9), acetic acid (4), and pyroligneous acid (5), have been used with varying success in soil disinfection. Most of these fungicides have the disadvantage of not being effective in the control of weeds, nematodes, and insect pests.

Steam was first employed for soil sterilization in 1893 by W. H. Rudd of Greenwood, Illinois. He placed the soil in a box or chamber in which were perforated steam pipes. This method is still used but it requires more handling of the soil than other methods and is not practical for large quantities of soil. A modified method in the use of steam is the buried perforated pipe, or tile system. The pipe or tile is laid 12 to 14 inches deep, and 18 to 20

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[2] The author expresses appreciation to W. S. Beach, F. D. Kern, H. W. Thurston, E. L. Nixon, and J. W. Sinden, of the Department of Botany, The Pennsylvania State College, for their assistance during this experiment and their suggestions in the preparation of the manuscript; also John E. Nicholas, of the Department of Agricultural Engineering, for making available certain equipment.

inches apart in the soil to be treated. The steam then is injected into the soil until the temperature has risen sufficiently high to effect partial sterilization.

The inverted steam pan method was first used by A. D. Shamel, of the United States Department of Agriculture, in 1904 to treat tobacco seedbeds. There are many variations in the construction and size of the pans and in the position of the steam inlet. The soil is covered with an inverted pan and steam is forced underneath it. After steaming is discontinued, the pan may be left in place or the soil covered with burlap or paper to conserve the heat and prevent recontamination. This has been the most efficient and practical method for outdoor seedbeds. The steam rake has been used somewhat but is less effective than either the buried tile or the inverted pan.

Hot water treatment of soil is a satisfactory method for pots or flats, or where small quantities of soil are involved. Pots filled with soil are immersed for five minutes in water at a temperature of 208° F.

Electric heat was found practicable by Newhall and Nixon (17) for the treatment of small quantities of soil.

Treatment of large quantities of soil by the use of chemicals is usually prohibitive because of the high cost. Chemicals have the further disadvantage of inefficient control of weeds and insect pests and, in many cases, considerable delay in seeding after treatment.

Treatment by heat, while effective and relatively inexpensive, has not been used more generally because of lack of convenient equipment. The more general use of gasoline engines and tractors for power has resulted in a scarcity of steam engines in many localities. The South, in particular, has need for an efficient and practical means of soil disinfection for tobacco and vegetable seedbeds.

The study here reported involves a new method of soil treatment, using a combination of heat and a chemical.[3] The principle of operation of this apparatus differs from the steam boiler in that water or chemical solutions are vaporized while being pumped through heated coils. When a volatile chemical, such as formaldehyde, is used in a solution, separation of the chemical by distillation is prevented, and the concentration of the chemical vapor is constant. In a steam boiler these chemicals are distilled off at their respective boiling points.

Objects of the Experiments

1. To determine whether formaldehyde in combination with steam-vapor would result in greater efficiency of disinfection than steam-vapor alone, and greater depth of penetration of formaldehyde than a drench.

2. To determine the effect of initial moisture content of the soil on the penetration of steam-vapor.

3. To compare the new apparatus with a steam boiler with respect to efficiency and cost.

[3] The apparatus used in these experiments was the "Hypressure Jenny," manufactured by the Homestead Valve Manufacturing Company, Coraopolis, Pa.

Description of the Apparatus

A one horsepower gas engine, to which is directly connected an air blower, a fuel oil burner, and a solution pump, is used in the operation of this machine. The constant capacity solution pump delivers the solution from a tank to the special multiple generator coils. Simultaneously, oil is being pumped from the fuel tank through the saturation selector to the burner jet (Fig. 1). In passing through the generator coils the solution is heated to the temperature and pressure necessary to produce a thoroughly conditioned vapor.

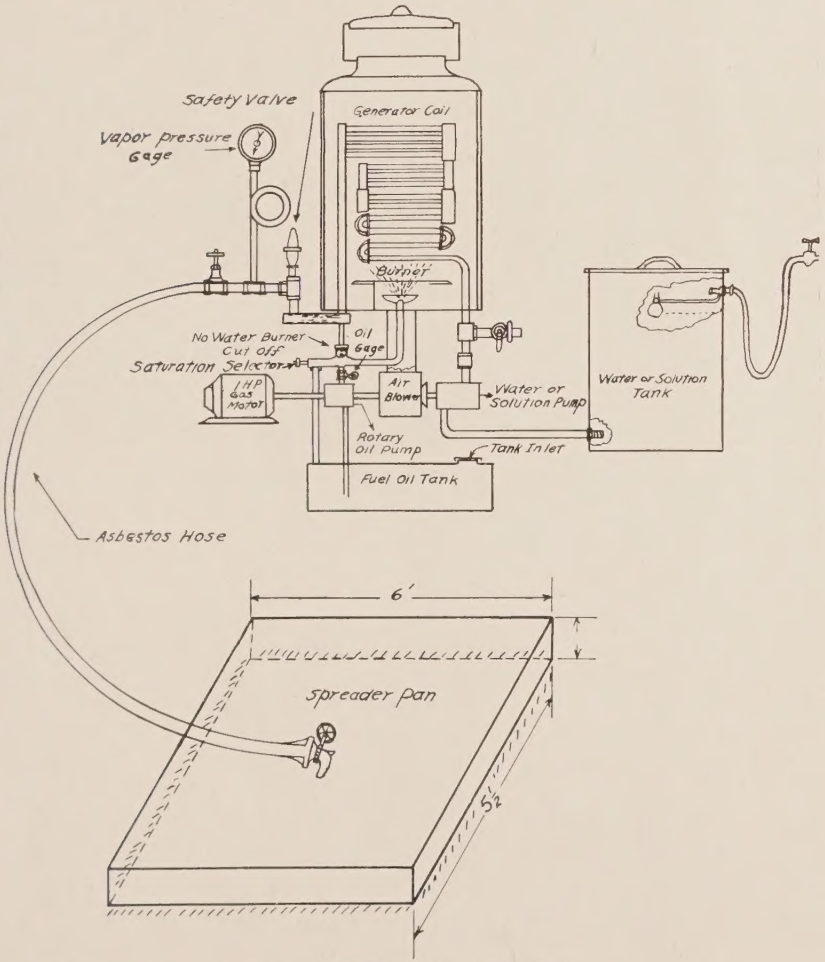

FIG. 1.—DIAGRAM OF APPARATUS

A manually adjustable saturation selector controls the oil pressure on the burner jet. Changing the oil pressure changes the ratio of fuel and solution fed to the heating coils and varies the amount of moisture in the vapor,

regardless of the vapor pressure carried. For soil disinfection work the maximum oil pressure is carried in order to develop the most heat. The capacity of the pump is reduced to two-thirds of a gallon per minute.

No restriction is encountered in the outlet line; this permits a direct and rapid movement of the vapor to the pan as soon as it is generated in the coils.

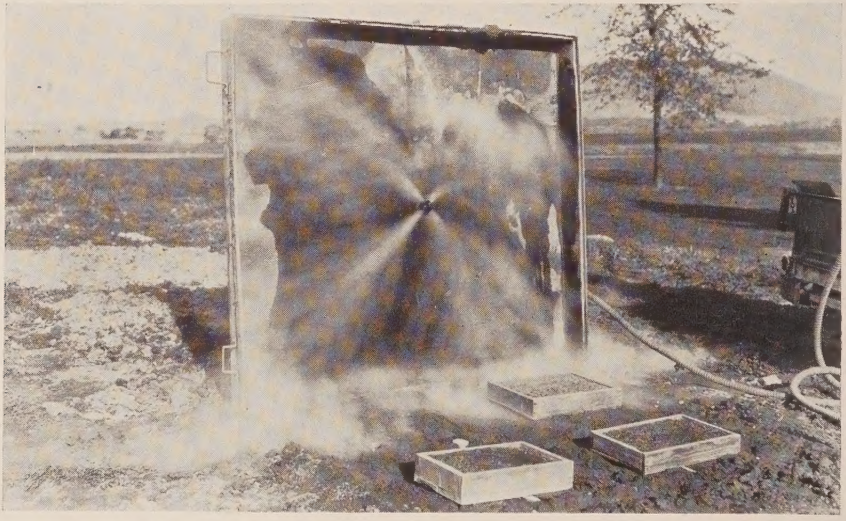

FIG. 2.—INVERTED PAN, SHOWING VAPOR DISTRIBUTOR

Sterilizing Pan.—A 2-section pan, 5½ by 6 feet, (Fig. 2) was used in the experiments. It was constructed of two layers of galvanized iron, insulated between with one-half inch of patented insulation material on the top and four sides. The galvanized iron was soldered on the inside to make it steam-tight. The outside was perforated by drilling ⅝-inch holes to allow the escape of any water that might leak through the inside layer and reduce the insulating effect. Around the bottom of the pan was bolted a ¼-inch by 2-inch piece of strap iron, extending one inch past the edge. This strengthened the pan and made pressing into the soil easier.

The inlet to the pan was at the top center, with a distributor beneath the top (Fig. 2). The distributor consisted of a 4-way ¾-inch pipe fitting, with one side drilled out and a ¾-inch nipple welded into it. The nipple was extended through the pan and connected with the hose. This arrangement insured equal distribution of the vapor over all parts of the soil.

Effect of Formaldehyde in Combination with Steam Vapor in Killing a Damping-Off Fungus

Anderson and McClintic (2) state: "It is a well-known principle in the use of disinfectants that, within certain limits, the higher the temperature at which the disinfectant is used, the greater its germicidal properties." I. E. Melhus (13) states: "The increase in germicidal properties of disinfectants

through the influence of heat is not the same for all disinfectants; some, such as formaldehyde, are more strongly influenced than others."

The only record on the combination of chemicals with steam for the disinfection of soil is the report by Hunt, O'Donnell, and Marshall (10) on eradication of potato wart, *Synchytrium endobioticum*. They sprinkled the soil with a solution of formaldehyde and then steamed it with an inverted pan. Using Schryver's test,[4] they found that formaldehyde applied in this way did not penetrate the soil more than about one inch. This method was repeated in the experiments here reported, and their results were confirmed.

Formaldehyde is very difficult to volatilize in a water solution. Melhus reports that boiling a 1/200 solution of formaldehyde for 15 minutes resulted in a loss of only .00008 gram per cubic centimeter. In general, the strength of the solution remains approximately the same throughout heating or boiling. This suggests the reason why formaldehyde applied as a drench does not penetrate the soil deeper than the water that carries it.

Methods.—The principle of operation involved makes it possible to combine formaldehyde in widely varying amounts with steam vapor at high temperatures. The formaldehyde was put in the tank with water and the solution vaporized under a vapor pressure of 150 pounds at a temperature of 365.9 degrees Fahrenheit. Samples of soil were taken at 2, 4, 6, 8, 10, and 12 inches deep, and formaldehyde penetration determined by the use of Schryver's test.

The effectiveness of formaldehyde applied in combination with the steam-vapor [5] was determined by the following method. An undetermined species of

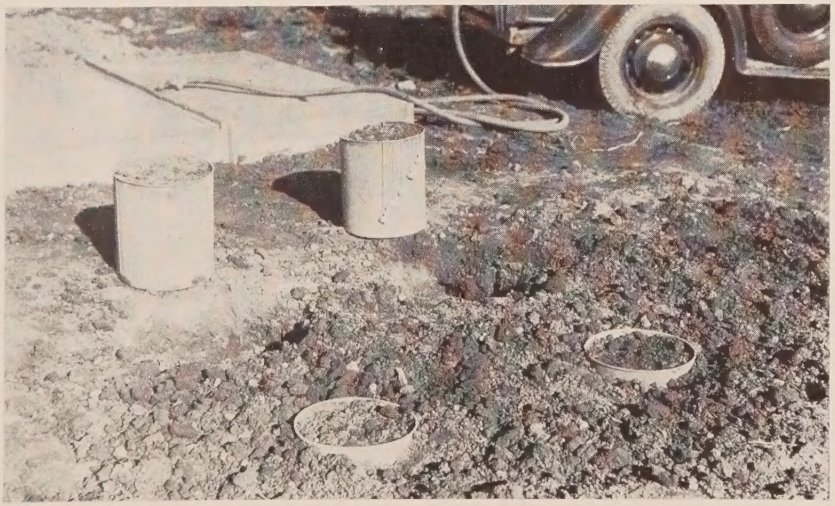

FIG. 3.—PREPARATION FOR EXPERIMENT ON DEPTH OF KILL OF A *FUSARIUM* SHOWING ARRANGEMENT OF VIALS AT VARIOUS DEPTHS

[4] Schryver—"Proc. Roy. Soc. Lond.," B, 1910, 82, 226.
[5] The term applied to the vaporized water produced by this apparatus.

Fusarium, isolated from an infected dianthus seedling and grown in pure culture, was transferred to steam-sterilized rye and allowed to grow on this medium until it was well established. This fungus was selected because it grows rapidly and has a characteristic type of growth on corn meal agar. Five to six of the rye grains, overgrown with the fungus, were placed in 25 by 15 mm. specimen vials from which the bottoms had been broken. Both ends were plugged with loose cotton wool to permit free movement of vapor through the vials. The vials were tied in cheesecloth bags and placed at depths of 4, 6, 8, 10, and 12 inches in cylindrical containers or cans (Fig. 3). The cans were placed in the ground, level with the soil. The length of treatment and the strength of the formaldehyde were varied in such a manner as to apply formaldehyde at the rate of 8, 12, and 16 ounces per 100 square feet. These amounts are 1/16, 1/10.6, and 1/8 of the quantity commonly recommended for drenching soil, which is 8 pounds to 100 square feet.

When the ground had cooled, 16 to 24 hours after treatment, the vials were removed to the laboratory and the grains transferred to petri dishes on corn meal agar. At the end of 48 hours, growth of the *Fusarium* on the plates was recorded.

Results.—The results of using a combination of formaldehyde and steam vapor in comparison with steam-vapor alone, as measured by the killing of a *Fusarium,* are recorded in Table 1. There was consistently a greater depth of kill where formaldehyde was added. The average depth of kill for the 10-minute period of disinfection, where 8 ounces of formaldehyde per 100 square feet had been used, was one inch, as compared with no kill where steam-vapor alone had been used.

In the 15-minute period, formaldehyde solution vapor, at a dilution that would deliver 8 ounces per 100 square feet was effective two inches deeper than steam-vapor alone. The *Fusarium* was killed at an average depth of six inches, while formaldehyde penetrated to an average depth of seven inches. With steam-vapor alone, killing took place to an average depth of only four inches.

In the 20-minute periods, two concentrations of formaldehyde solution were used, one applying 8 ounces of formaldehyde and the other 16 ounces per 100 square feet. With eight ounces, killing resulted up to a depth of 7.6 inches, and the presence of formaldehyde was indicated by a positive test at an average depth of 8.2 inches. For the same period steam-vapor alone killed to an average depth of 5.2 inches, or a difference in the depth of kill of 2.4 inches. When 16 ounces were used, there was a difference in depth of kill of three inches in favor of formaldehyde vapor, but the depth of kill was not so deep as where eight ounces were used, since treatment was made somewhat later in the fall, when the soil was cold and wet.

The 25 and 30-minute periods of treatment resulted in disinfection to a depth of 8 inches in both cases. There was little if any increase in depth of kill resulting from the addition of formaldehyde.

These results indicate that with the inverted pan method disinfection cannot be expected to a greater depth than 8 or 10 inches in this soil type—Hagerstown silt loam. In sandy soil, disinfection may be expected to a greater depth. These results are in accord with those obtained by other investigators.

Table 1 shows a correlation between formaldehyde penetration and depth of kill of the *Fusarium.* In every case where formaldehyde solution vapor was

used, the soil samples gave a positive test for the chemical at the same depth or several inches deeper than that at which the organisms were killed. It is apparent from the difference in the depth of the kill of this fungus that small quantities of formaldehyde (8 to 16 ounces per 100 square feet) added to the water are more effective than steam-vapor alone.

When the soil was drenched with formaldehyde at the rate of 8 ounces to 100 square feet in a dilution that would give one pint of solution to the square foot, and followed by steaming for 20 minutes, the samples gave a positive test for formaldehyde to an average depth of only three inches. This was the depth to which the solution had percolated. Hunt, O'Donnell and Marshall (10), using the same method, found that formaldehyde penetrated from 1 to 4 inches. When the soil was treated with this same quantity of formaldehyde in the form of vapor for 20 minutes, the average penetration in 10 tests was 8.2 inches; in all cases it was at least 6 inches. This shows that formaldehyde, applied as a vapor, can be driven into the soil as deep as steam-vapor (Table 2).

TABLE 1. RESULTS OF USING STEAM AND FORMALDEHYDE VS. STEAM ALONE AS DETERMINED BY THE DEPTH OF KILL OF THE FUSARIUM AND THE DEPTH OF FORMALDEHYDE PENETRATION

Steam and Formaldehyde						Steam-vapor
Length of time treated (minutes)	Average moisture content of soil (per cent)	Amount of sol. or H_2O applied per 33 sq. ft. (gallons)	Amount of formaldehyde applied per 100 sq. ft. (ounces)	Depth of kill of Fusarium (inches)	Depth of formaldehyde penetration (inches)	Depth of kill Fusarium sp. (inches)
10	17.94	6.66	8	2	4	0
10	17.94	6.66	8	2	4	0
10	17.94	6.66	8	0	2	0
10	17.94	6.66	8	0	2	0
15	16.71	10.00	8	6	8	2
15	16.71	10.00	8	6	8	4
15	9.01	10.00	8	6	6	4
15	9.01	10.00	8	6	6	6
20	17.97	13.30	8	6	6	4
20	17.97	13.30	8	6	6	4
20	14.56	13.30	8	10	12	6
20	14.56	13.30	8	10	12	8
20	17.50	13.30	8	6	6	4
20	17.50	13.30	8	8	10	6
20	16.83	13.30	8	10	10	6
20	16.83	13.30	8	6	8	4
20	16.83	13.30	8	8	8	6
20	16.83	13.30	8	6	8	4
20	17.49	13.30	16	6	8	4
20	17.49	13.30	16	6	8	4
20	17.49	13.30	16	6	8	2
20	17.49	13.30	16	6	8	2
20	17.94	13.30	16	6	8	2
20	17.94	13.30	16	4	8	2
20	17.94	13.30	16	4	8	2
20	17.94	13.30	16	6	8	2
25	14.56	16.60	12	8	8	8
30	14.56	20.00	16	8	10	8
Summary						
10	17.94	6.66	8	1.0	3.0	0.0
15	12.86	10.00	8	6.0	7.0	4.0
20	16.70	13.30	8	7.6	8.2	5.2
20*	17.71	13.30	16	5.5	8.0	2.5
25	14.56	16.60	12	8.0	8.0	8.0
30	14.56	20.00	16	8.0	10.0	8.0

* Soil extremely cold and wet, partially frozen.

TABLE 2. PENETRATION OF FORMALDEHYDE WHEN APPLIED AS A DRENCH AND WHEN APPLIED AS A VAPOR

Method of treatment	Length of time treated (minutes)	Average moisture content of soil (per cent)	Amount of water applied as steam-vapor per 100 square feet (gallons)	Amount of formaldehyde applied per 100 sq. ft. (ounces)	Depth of formaldehyde penetration (inches)
Formaldehyde drench* followed by steaming	20	17.01	13.3	8	2
	20	17.01	13.3	8	4
	20	17.01	13.3	8	2
	20	17.01	13.3	8	4
Average	20	17.01	13.3	8	3
Formaldehyde applied as a vapor	20	17.97	13.3	8	6
	20	17.97	13.3	8	6
	20	14.56	13.3	8	12
	20	14.56	13.3	8	12
	20	17.50	13.3	8	6
	20	17.50	13.3	8	10
	20	16.83	13.3	8	10
	20	16.83	13.3	8	8
	20	16.83	13.3	8	8
	20	16.83	13.3	8	8
Average	20	16.70	13.3	8	8.2

*Solution applied at the rate of one pint per square foot.

Discussion.—In all the experiments in which the combination of formaldehyde and steam-vapor was compared with steam-vapor alone for killing the *Fusarium*, the former treatment gave significantly greater depth of kill than did the latter. The addition of formaldehyde gave the greatest benefit in the shorter periods of treatment (15 minutes) and for soil which was too wet for good steaming. The addition of formaldehyde was less advantageous in the 30-minute period of treatment and for soil which was sufficiently dry for good penetration of steam. In a heavy Hagerstown silt loam, formaldehyde could not be driven beyond a depth of 10 inches. This is a depth to which disinfection is possible with steam alone under favorable conditions for steaming.

The difference in depth of kill of the *Fusarium* indicates that addition of formaldehyde in small quantities, driven into the soil as a vapor, is effective in disinfection. Tests for this chemical showed that it had penetrated as far as or beyond the depth at which the organism was killed. Checks indicated that heat alone was not responsible for killing at this depth.

Formaldehyde vapor can be driven into the soil as deeply as steam, the depth depending on the type and condition of the soil. When it is sprinkled on the soil in solution and the soil then steamed, it will not penetrate to a depth greater than the solution carrying it.

The apparatus used in this experiment is the first equipment available that makes it possible to combine formaldehyde and steam-vapor for soil disinfection. Because of this feature it has an advantage over the steam boiler when it is desirable to shorten the period of treatment or to disinfect soil under adverse conditions.

Effect of Initial Moisture Content of Soil on Penetration of Steam-Vapor

Most investigators of steam disinfection of soil have stressed the importance of the initial moisture content. A soil with a high moisture content is more difficult to disinfect with steam for two reasons: first, the specific heat of the water held by the soil is approximately five times that of the soil itself; second, wet soils are more easily puddled or sealed; this results in closing the pore space which is necessary for the penetration of steam.

Methods.—Two methods were used. In the first method, four lots of Hagerstown silt loam were made up with different moisture contents. Lot 1 was dried in the oven and the moisture content reduced to 2.48 per cent. Lot 2 contained 10.17 per cent moisture. To Lots 3 and 4 water was added to increase the moisture content to 20.52 and 34.21 per cent respectively.

These soils were put in four cans, 11 inches in diameter and 13 inches in depth. The cans were filled in the same manner, to insure like compactness of the soil. They were placed in the ground even with the surface, and so arranged that each had the same relative position from the center and corners of the pan. The ground was spaded and prepared around the outside of the cans. The pan was placed over the cans and steam was applied for 30 minutes at a vapor pressure of 150 pounds at the gauge. The pan was allowed to remain in place for an additional five minutes after the steam-vapor was shut off. Immediately after the pan was removed, thermometers were placed in each can and the temperature readings recorded in three different positions at depths of 2, 4, 6, 8, and 10 inches. These readings were repeated at 10, 20, 40, 60, 80, and 140 minutes thereafter. The average temperature was then computed for each depth.

In the second method, thermocouples were used to record the temperatures instead of thermometers. This method has an advantage in that temperatures may be recorded during the process of steaming. Readings with thermocouples are accurate, easily made, and can be obtained at many different positions within a can. This method was used to verify the results obtained by the use of thermometers and to obtain a record of the rise in temperature during the process of steaming.

Soils of known moisture content were prepared in the same manner as for the former method, 10 thermocouples being used in a single can. Figure 4 shows the location of the thermocouples in the container. Readings were taken in two different positions at depths of 2, 4, 6, 8, and 10 inches in each test. The soil was steamed for 30 minutes with 150 pounds of vapor pressure at the gauge, and the pan was allowed to remain in position for five minutes after steaming. Readings were taken at 5-minute intervals during the steaming process and after removal of the pan; and at 10-minute intervals until the soil had cooled to a temperature below that necessary for effective disinfection.

Results.—Figure 5 shows the average of three thermometer readings in soil with different moisture contents, taken at 2, 4, 6, 8, and 10 inches below the surface at the various periods after treatment and the trend of these temperatures as influenced by the moisture content of the soil. The temperature began to fall at the 2-inch depth, in all cases, as soon as the pan was removed. At the

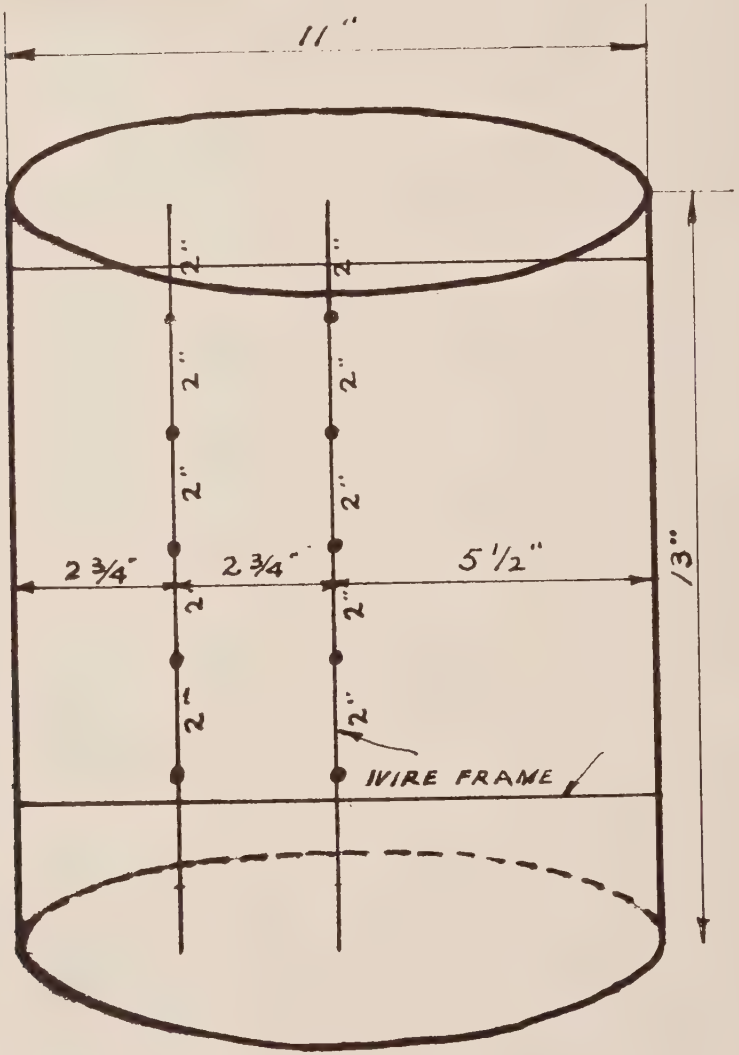

FIG. 4.—LOCATION OF THERMOCOUPLES MEASURING SOIL TEMPERATURE

4-inch depth the temperature continued to rise for approximately 10 minutes after the pan was removed, with the exception of the dried soil, which attained a temperature of 206.6°F. before the pan was removed; here there was a continued drop in temperature. At the 6-inch depth, the temperature continued to rise for approximately 40 minutes except in the dried soil where it was 203°F. before the removal of the pan.

At the 8-inch depth the temperature continued to rise for approximately 60 minutes in the three soils with the higher moisture content. The dry soil had reached a temperature of 197.6°F. before the pan was removed and dropped

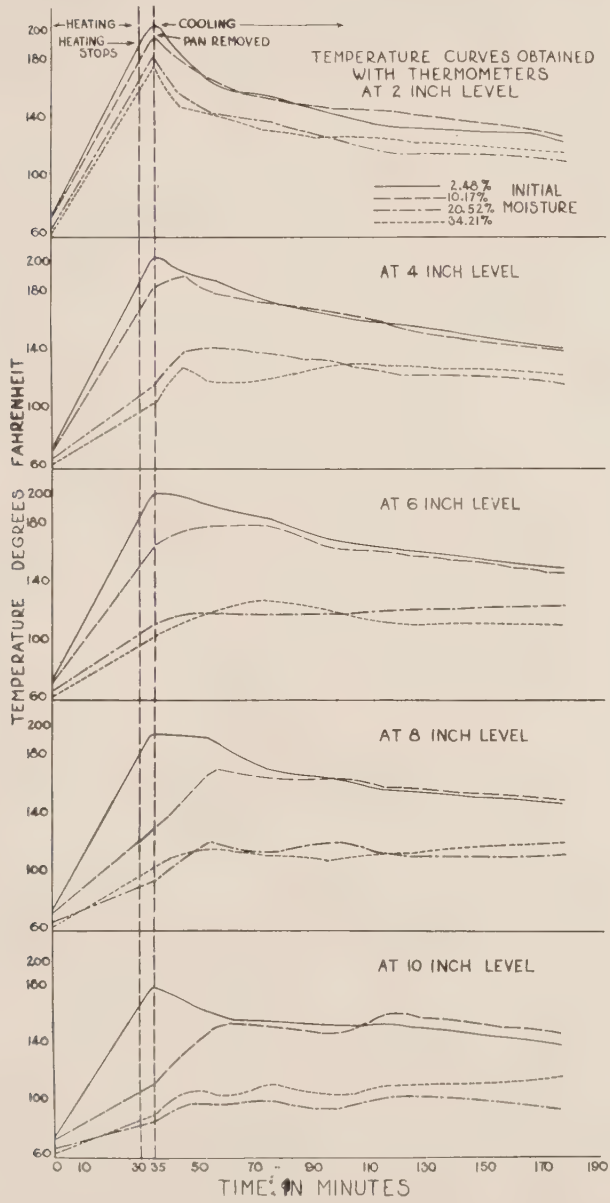

FIG. 5.—TEMPERATURE CURVES OBTAINED WITH THERMOMETERS AT VARIOUS DEPTHS

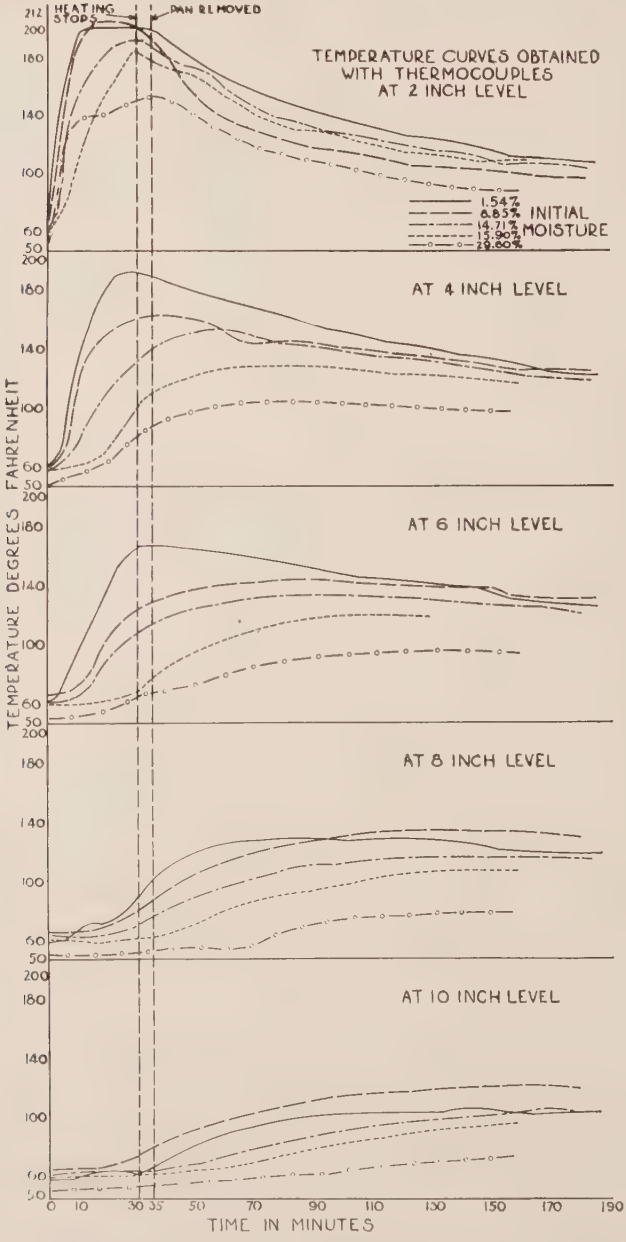

FIG. 6.—TEMPERATURE CURVES OBTAINED WITH THERMOCOUPLES AT VARIOUS DEPTHS

gradually thereafter. At the 10-inch depth the three soils with the higher moisture content continued to rise for 10 minutes but remained about constant for the remainder of the 140-minute period. Again the temperature in the dry soil dropped continuously from the time the pan was removed.

The average maximum temperatures sustained for 40 minutes by soils of different moisture contents are given in Table 3. Figure 6 shows the effect of the initial moisture content of the soil on the rise and drop of temperature at 2, 4, 6, 8, and 10-inch depths when steamed under an inverted pan for 30 minutes, as recorded by thermocouples.

The drier soils showed a more rapid rise in temperature during the steaming process. The soils with 1.58 per cent and 8.85 per cent moisture reached maximum temperature at the 2-inch depth in 10 to 15 minutes, while soils with higher moisture content required a longer period to reach maximum temperature at the same depth.

TABLE 3. AVERAGE MAXIMUM TEMPERATURES SUSTAINED FOR 40 MINUTES BY SOILS OF DIFFERENT MOISTURE CONTENTS*

Initial moisture content per cent	Temperatures in degrees Fahrenheit				
	2-inch level	4-inch level	6-inch level	8-inch level	10-inch level
2.48	179.0	192.5	196.1	188.9	168.8
10.17	176.9	183.5	176.9	168.8	154.9
20.52	156.5	139.3	124.3	115.3	97.3
34.21	151.7	124.3	123.0	114.8	111.2

* Each figure in this table is an average of three readings.

In general, soil at the 4 and 6-inch depths heated less rapidly. At the 8 and 10-inch depths, little change in temperature resulted during the 30-minute treatment but the temperature continued to rise after steaming. At the end of the 150-minute period the temperatures were approximately the same for all depths. The temperature changes after the removal of the pan were very similar to those obtained with the thermometers.

Hunt, O'Donnell, and Marshall (10) give temperature changes in soil under a steam pan at 1, 4, and 7 inches below the surface for different pressures and for different lengths of time. They report, "In most cases the temperature began to fall at the 1-inch depth almost as soon as the steam was shut off. At the 4-inch depth the temperature continued to rise for several minutes after the steam was shut off. At the 7-inch level the temperature continued to rise for a considerable time after the steam was shut off, except where the temperature of 100°C. had previously been reached." These temperature readings were taken on soils with approximately the same initial moisture content, 25 to 27 per cent, hence they did not show the difference in temperature due to variations in amount of initial moisture.

Discussion.—The penetration of steam-vapor into Hagerstown silt loam is greatly influenced by the initial moisture content. At a 6-inch depth the maximum temperature ranged from 171.5°F. with soil of 1.58 per cent moisture to

97.6°F. with soil containing 29.6 per cent moisture. At the 4-inch depth the maximum temperature ranged from 197.4°F. (1.58 per cent moisture) to 108.9°F. (29.6 per cent moisture).

Assuming that 150°F. is essential to assure the death of most pathogenic soil organisms, the temperature would be raised sufficiently high to kill them at the 4-inch depth in soil up to approximately 16 per cent moisture; at the 6-inch depth, to approximately 8 per cent moisture.

Treatment of Seed Flats under an Inverted Pan With Steam Vapor and Formaldehyde

Greenhouse flats were treated and planted with vegetable, flower, and tobacco seeds preliminary to the disinfection of outdoor seedbeds. Flats were treated with steam-vapor, alone and in combination with formaldehyde vapor. Flats were also treated in a steam box for 90 minutes at 10 to 12 pounds pressure, for comparison with those treated by the steam-vapor method. A total of 63 flats was disinfected and seeded, including the checks. The details of these preliminary tests are not presented here, but the results are of interest. The application to flats of .097 ounce of formaldehyde per square foot as a vapor in 15-minute periods protected seedlings against damping-off during and after seed germination just as well as the steam box method for 90 minutes. When soils were treated with formaldehyde in combination with steam-vapor, it was possible to plant most vegetable, flower, and tobacco seeds 24 hours after treatment. Treating seed flats with small amounts of formaldehyde vapor, reduced the need of seed disinfection before planting.

Sterilization of Tobacco Seedbeds

Method.—In the tobacco experiment plots in Lancaster county, Pennsylvania, a comparison was made between seedbeds steamed with a 16 horsepower steam boiler for 30 minutes, and those treated by the steam-vapor generator for 20 or 30-minute periods, using 32, 16, 8 and 4 ounces of formaldehyde per 100 square feet. All the beds were seeded approximately 24 hours after treatment. Counts were made of tobacco seedlings on a representative area, 10 by 10 inches, 30 days after treatment. Records were kept of the quantity of fuel oil and gasoline used and actual operating costs were computed.

Results.—There appeared to be no significant difference resulting from the several methods of treatment. There was the usual great difference between the untreated checks and the disinfected beds, as far as acceleration of growth, control of weeds, and general appearance of the plants were concerned. In most cases, the weeds completely crowded out the tobacco plants on untreated soil. At transplanting, no significant difference could be noticed in the growth of the plants among the plots receiving the various vapor treatments. There was no formaldehyde injury in the seedbeds like that in seed flats treated with comparable amounts of formaldehyde for 15 minutes. There was no damping-off of the seedlings. In practically all cases the plants pulled from beds disinfected with the steam-vapor were as large and as healthy as those from beds treated with the steam boiler.

Cost.—A record was kept of fuel consumed in the disinfection of approximately 1000 square feet of tobacco seedbeds.
Cost per hour of operation:

Fuel oil, 3.5 gallons per hour @ $.065	$.2275
Gasoline, 1/6 gallon per hour @ $.18	.03
Labor for operating @ $.40 per hour	.40
Total	$.6575

This figure does not include the cost of the apparatus, or the cost of the water used. The size of the pan used in this experiment was 33 square feet. The treatments were for 30-minute periods, when steam-vapor alone was used. Thus the cost of operation was approximately one cent per square foot.

When formaldehyde was combined with steam-vapor and applied at the rate of 16 ounces per 100 square feet, the treatment could be shortened to 20 minutes with as satisfactory results as steam-vapor alone for 30 minutes. Using commercial formaldehyde at 15 cents per pound, and shortening the treatment to 20 minutes, the cost was reduced to approximately 80 cents per 100 square feet, compared with $1 per 100 square feet with steam-vapor alone.

The cost of disinfecting soil with this equipment is within the range of that reported by other investigators. Beinhart (3) reports that the charge for steaming varies in tobacco-growing sections from 50 cents to $1 per 100 square feet, or from $6 to $12 per day. The contractors may or may not furnish the pan and fuel. Newhall (14) gives the cost of steaming by the pan method as $.006 to $.012 per square foot. Hunt, O'Donnell, and Marshall (10) report the cost as approximately $15 per day. This would average about $.046 per square foot when steamed for 90 minutes, or $1.52 per 100 square feet when steamed for 30 minutes.

The average cost of steaming tobacco seedbeds with a steam engine for 30 minutes in Lancaster county in the spring of 1935, was $1.30 per 100 square feet. Table 4 gives the cost of soil disinfection as reported by various investigators.

TABLE 4. COST OF SOIL DISINFECTION

Investigator	Method	Cost per 100 square feet
Beinhart, 1918 (3)	Steam pan	$ .50-$1.00
Hunt, O'Donnell, and Marshall, 1918 (10)	Steam—90 minutes	$4.60
	30 minutes	$1.52
Newhall, A. G., 1927 (14)	Steam pan	$ .60-$1.20
Johnson, James, 1930 (12)	Steam pan	$1.00-$2.00
Beachley, K. G., 1936 Lancaster County	Steam pan—30 minutes	$1.30
	Steam vapor—30 minutes	$1.00
	Formaldehyde drench* (material only)	$1.20
	Formaldehyde and steam-vapor for 20 minutes, using 16 ounces formaldehyde per 100 sq. ft.	$ .80
Doran, 1928 (4)	Acetic acid (material only)	$ .53

*8 pounds formaldehyde per 100 square feet, as recommended by Johnson (12).

Discussion.—Comparing the results obtained from treating seedbeds and seedflats, it is evident that the principle of the apparatus used offers an efficient and relatively inexpensive means of soil disinfection.

Other advantages of this type of equipment for soil disinfection are its low initial cost, its compactness and portability as compared with the traction steam boiler and its adaptability for other uses. The machine may be obtained with a greater capacity than the one used in this experiment.

Summary

This investigation was concerned with the efficiency of an apparatus which combines heat and chemical treatments as a means of soil disinfection.

1. Formaldehyde in combination with steam-vapor as applied with this apparatus made it possible to shorten the period of soil treatment with the inverted pan and increase the efficiency of this method in disinfecting cold and wet soils.

2. Vaporized formaldehyde was driven into the soil as deeply as steam, while the same amount of formaldehyde applied as a drench penetrated only as deep as the water carrying it.

3. By combining as small a quantity of formaldehyde as one pound per 100 square feet with steam-vapor, a 20-minute treatment was as effective in the disinfection of seed beds as a 30-minute treatment with steam-vapor alone.

4. The initial moisture content of soil is a limiting factor in the penetration of steam-vapor. In Hagerstown silt loam, disinfection to a 6-inch depth resulted with 30 minutes steaming in soil containing not more than 15 per cent moisture.

5. The application to seed flats of .097 ounce of formaldehyde per square foot as a vapor in 15-minute periods, protected seedlings against damping-off during and after seed germination as well as the steam box method for 90 minutes, and also reduced the need for seed treatment.

6. When soil was treated with formaldehyde in combination with steam-vapor it was possible to plant most vegetable and flower seeds 24 hours after treatment.

7. Treating tobacco seedbeds with steam vapor, alone or in combination with formaldehyde, gave as satisfactory results as those treated with the steam engine.

8. The cost of disinfecting seedbeds, using steam-vapor alone for 30 minutes, was approximately $1 per 100 square feet.

9. By combining one pound of formaldehyde per 100 square feet with the steam-vapor and shortening the period of treatment to 20 minutes, the cost was reduced to approximately 80 cents per 100 square feet.

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